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# Some Estimates of the Contribution of Information Technology to Consumer Welfare

by

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CCS WP # 161, Sloan School WP # 3647-94

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**Some Estimates of the Contribution of Information Technology to Consumer Welfare**

ABSTRACT

Over the past decade, American businesses have invested heavily in information technology (IT) hardware. Unfortunately, it has been difficult to assess the benefits that have resulted. One reason is that managers often buy IT to enhance customer value in ways that are largely ignored in conventional output statistics. Furthermore, because of competition, firms may be unable to capture the full benefits of the value they create. This undermines researchers' attempts to determine IT value by estimating its contribution to industry productivity or to company profits and revenues.

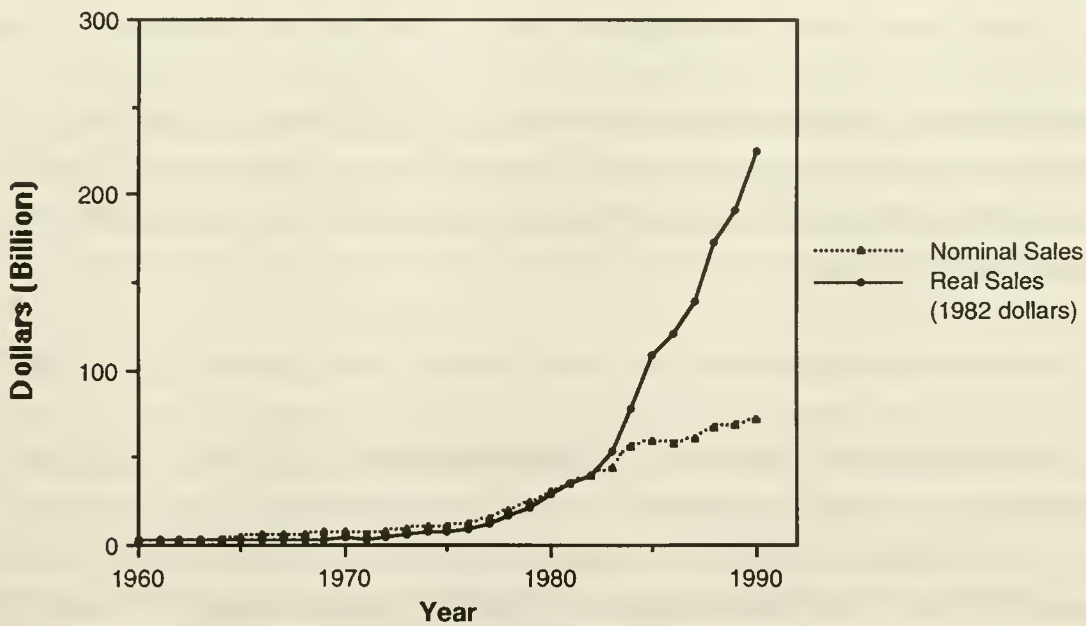
An alternative approach is to estimate the consumer surplus from IT investments by integrating the area under the demand curve for IT. This methodology does not directly address the question of whether managers and consumers are purchasing the optimal quantity of IT, but rather assumes their revealed willingness-to-pay for IT is an accurate indicator of their preferences. Using data from the U.S. Bureau of Economic Analysis, we estimate four measures of consumer welfare, including Marshallian surplus, exact surplus based on compensated (Hicksian) demand curves, a non-parametric estimate, and a value based on the theory of index numbers. Interestingly, all four estimates indicate that in our base year of 1987, IT spending generated approximately $50 billion to $70 billion in net value in the U.S. Our estimates imply that the value created for consumers from spending on IT is about three times as large as the amount paid to producers of IT equipment, providing a new perspective on the IT value debate.

## 1. Introduction:

1.1 The Question of IT Value

In 1990, American businesses spent over $43 billion on "office, computing, and accounting machinery" (OCAM)[1]. Nominal spending has increased substantially over the past several decades and in real terms the increase has been even more dramatic because of annual declines exceeding 20% in the real price of computing power (graph 1 and graph 2).

While the economic significance of this spending is apparant in the rise of firms such as Microsoft and Intel, and before them, IBM and DEC, the benefits to consumers in the broader economy have been more difficult to quantify. For instance, Baily and Gordon (1988) ask "Where is the black hole into which all those computers are disappearing?" and government statistics suggest that the service sector, which is the largest consumer of computers, has had only insignificant productivity growth in over a decade.




**Graph 1. Real and Nominal Purchases of Computers.**

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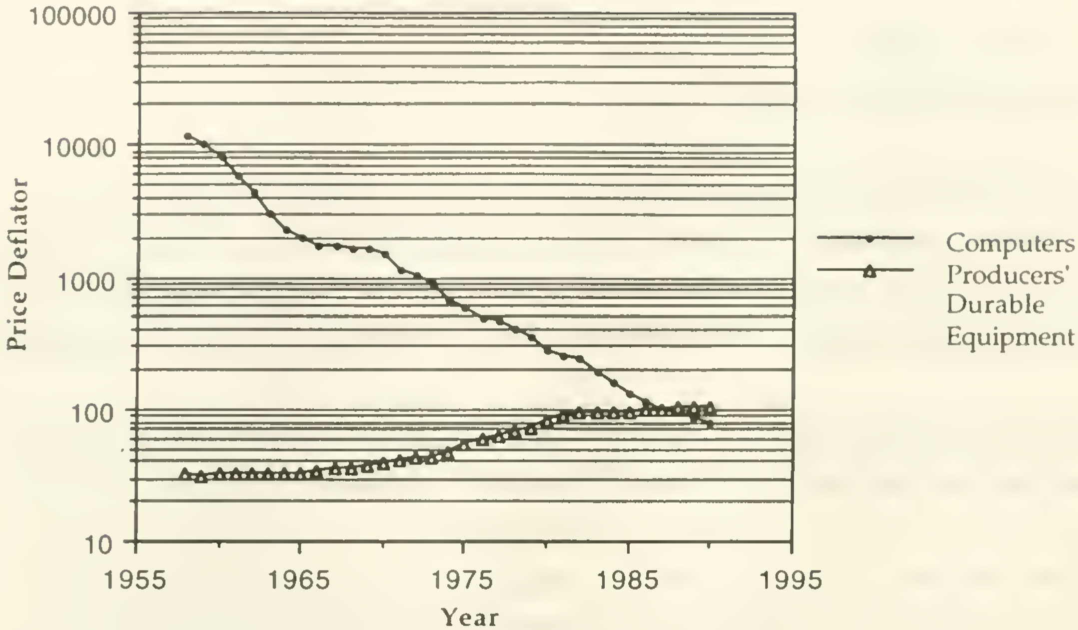
[1] OCAM is defined by the US Bureau of Economic Analysis to include such office machinery as calculators as well as computers




**Graph 2. The cost of computing has declined substantially relative to other capital purchases.**

Yet, there must be more to the impact of computers than meets the statistician's eye. A visit to Wall Street, or any large bank for that matter, will reveal products, services and transaction processing capabilities that would have been simply impossible without enormous computer power. For instance, the New York bank deposit turnover ratio (annual value of transactions divided by deposits on hand) has increased to 3804 in 1990 from just 156 in 1960.

A number of explanations have been put forth for this paradox, but among the most compelling is the inherent difficulty in applying traditional productivity metrics to the types of benefits enabled by information technology (IT) (Brynjolfsson, 1993). Managers invest in IT not only to reduce costs, but also to improve quality, increase product variety, speed up responsiveness and enhance customer service. However, these intangible benefits are largely ignored in conventional output and productivity statistics because they are difficult to measure, aggregate, and value. In practice, productivity measurement focuses on increases in the physical quantity of production and reductions in costs, especially head count.

Furthermore, because of competition, firms are typically unable to capture the full value of the intangible benefits they create but nonetheless find that they must provide these benefits

as the "cost of staying in the game". The ultimate beneficiaries of lower prices, increased quality or better customer service are consumers. This undermines researchers' attempts to estimate value looking at company profits or revenues. Thus, there may be a fundamental clash between the sources of value created by computers and the metrics that researchers have been using.

### 1.2 Preview of the paper

In this paper, we depart from the approach of estimating production functions and firm performance. Instead, we consider the revealed preference of IT consumers who "put their money where their mouths are" every time they make a purchase. Specifically, we focus on the consumers' valuation and the economic concept of *consumer surplus.* Because data is available that enables fairly accurate estimates of the demand for IT, this approach provides a promising alternative to productivity, profit, or output-based estimates of the value of IT. Furthermore, since this approach requires different assumptions than those required for productivity calculations, it may enable us to better "triangulate" on the true value of computers and IT.

Our estimates indicate that in the 1980s, IT generated over $400 billion dollars in net value in the U.S. after subtracting the costs of expenditures over that period. In our base year of 1987, we estimate that computers created between $80 and $90 billion in value, compared to costs of about $40 billion. Furthermore, at current rates of price declines and spending growth, consumer surplus from computers is projected to reach over $200 billion annually by 1997.

The next section discusses the various approaches to estimating IT value with particular attention to the theory of consumer surplus which will be applied. Section three describes the features and limitations of data and the econometric methods used. The results are presented in section 4, including some sensitivity estimates. In section 5, we conclude with a summary and discussion of future directions for the work.

## 2. The Theory Underlying Three Approaches to IT Value Estimation

Economic theory suggests at least three general approaches for econometrically estimating the value of an input such as IT: 1) output and productivity estimation, 2) correlations

with performance metrics such as profits, revenues, or stock values, and 3) consumer surplus from derived demand.

2.1 Output and Productivity

The first approach is based on the idea that inputs can be related to outputs by a production function.

$$output = F(computers, labor, capital, etc.) \tag{1}$$

Thus, the only way for a firm to increase output is to increase at least one of the inputs, or to change its technology or management so that its production function becomes more efficient. This is the approach taken by Loveman (1988), Barua, Mukhudpadhyay and Kriebel (1991), Morrison and Berndt (1990) and Brynjolfsson and Hitt (1993), among others.[2] Typically a functional form for a production function is assumed and the parameters are econometrically estimated under the assumption that firms are minimizing costs or maximizing profits. For instance, in estimating a Cobb-Douglas production function such as (2), the parameter $\beta_1$ can be interpreted directly as the output elasticity of computers: the amount by which output will increase for a given increase in computer input.

$$Output = e^{\beta_0} Computers^{\beta_1} Labor^{\beta_2} Capital^{\beta_3} \tag{2}$$

A key assumption of this approach is that final output is reliably measured.

2.2 Business Performance Metrics

The second common approach is to measure the correlation between computer spending and some performance metric, as suggested by equation 3.

$$performance\ metric = F(Computers, Environment, Strategy, etc.) \tag{3}$$

Typical performance metrics used include (growth in) business profits, (growth in) sales, (growth in) market share, stock price appreciation, and various industry-specific measures.

[2] See Brynjolfsson (1993) for a review of this literature.

While there are numerous ways to operationalize such a relationship, they all seek to isolate the contribution of computers while controlling for other factors. (For instance, (Cron & Sobol, 1983; Dos Santos, Peffers & Mauer, 1993; Harris & Katz, 1989; Weill, 1992)). If managers are rational, economic theory predicts that in equilibrium, high computer investors would not, on average, perform any better than low computer investors by these metrics. If significant correlations are found, they should be interpreted as indicating an *unexpectedly* high or low contribution of information technology, as compared to the performance that was anticipated when the investments were made.

In addition, a key assumption of this approach is that businesses retain the value created by their investments in IT, or at least capture a significant portion of it.

## 2.3 Consumer Surplus from Derived Demand

A third approach is based on the theory of consumer surplus, which has been little-applied to the question of IT value. Consumer surplus uses the theory of demand to compute the total consumer benefit based on revealed spending patterns.

The demand curve for any good plots the price that buyers would be willing to pay for each incremental quantity of that good. Because all the infra-marginal consumers actually pay less than what they would be willing to pay, they get some surplus from the transaction. By adding up all these individual surpluses, or equivalently, by integrating the area under the demand curve between the old price ($p_0$) and the new price ($p_1$), one can deduce the total value of consumer surplus from a price change.

$$Surplus = \int_{P_0}^{P_1} \mathrm{Demand}(Price, Income)\mathrm{d}(Price) \qquad (4)$$

In a competitive market, it can be proven that producers who purchase an intermediate good will act as proxies for the ultimate consumers: they will purchase exactly the quantity that maximizes consumer welfare at any given price. Therefore, the area under the derived demand curve for the intermediate good will be the correct estimate of consumer surplus from the intermediate good (Schmalensee, 1976). Bresnahan (1986) has shown that the area under the derived demand curve is also the appropriate estimator for consumer surplus in regulated industries, and that when competition is imperfect, it will generally underestimate total surplus created by a price change.

A key assumption of this approach is that managers are, on average, choosing the right amounts of IT, given its price.

2.4 Comparing the Three Approaches

Equations (1), (3), and (4) above can each be used to assess the value created by spending on a given input to production. One or the other approach will be more appropriate depending on the precise question being asked and whether the required assumptions are realistic in the particular case being considered.

As discussed above, for IT there is reason to believe that the dimensions of output most affected by increased investments are poorly measured in final output statistics. As a result, they may be underestimated or even ignored in productivity calculations, especially at the aggregate level. This limits the applicability of approaches relying on the production functions such as equation (1). Furthermore, in fully competitive markets, all of the benefits of a price decline for an intermediate good may be passed on to consumers, because of "competitive necessity" (Clemons, 1991). This makes the approach embodied in business performance metrics such as equation (3) problematic. Finally, with a relatively new and uncertain technology such as computers, managers may have difficulty making correct investment decisions. This will tend to undermine the accuracy of estimates based on consumer surplus as in equation (4).

There are a number of reasons that it is worthwhile applying consumer surplus to derive estimates of IT value. First, applying this approach can tell us how much value the purchasers of IT think they are getting, and by identifying the extent and the sectors in which this differs from productivity or performance metrics, we should be better able to find the source of the discrepancy. For instance, by putting upper and lower bounds on the size of the "mistakes" we think are plausible, we can put upper and lower bounds on the total surplus created, and by comparing services (where output measurement is often poor) to manufacturing (where measurement is typically better) we can calibrate the size of potential measurement shortfalls.

Second, the errors in estimating IT value via productivity and business performance metrics are likely to lead to systematic underestimates of IT value, because of underestimates of output and the shift of benefits to consumers respectively. In contrast, consumer surplus

estimates are based on the willingness-to-pay of the purchasers of IT. While managers will certainly make mistakes in the amount of IT they purchase, there is less reason to believe that these mistakes will *systematically* lead to over- or underinvestment. Because the consumer surplus estimates will be approximately accurate if managers are as likely to make either mistake, there should be less bias in these estimates.[3]

Third, each of the three approaches are subject to *different* types of weaknesses. This makes it valuable to use a variety of methods to help triangulate on the true value of IT. In the past, efforts have focused on the productivity or the performance metric approach, to the neglect of consumer surplus.

Finally, judging the contribution of a technology by the amount that its consumers are willing to pay accords well with the long-standing economic tradition of taking the consumers' preferences as sovereign. Because many of the benefits of IT may be difficult for the statistician or accountant to measure, it seems especially appropriate to take heed of the actions of the parties who spend the most time evaluating the costs and benefits of each decision.

### 2.5 Definitions of Consumer Surplus

Although the basic concept of consumer surplus is simple, there are a number of ways of operationalizing it. Below, four basic approaches and the relevant formulae are described, including 1) Marshallian surplus, 2) exact surplus based on compensated (Hicksian) demand curves, 3) a non-parametric estimate, and 4) a value based on the theory of index numbers. Under the assumptions of perfect competition, each of these approaches is appropriate for use with either demand curves for final goods, or derived demand for intermediate goods. Later, we will discuss the significance of relaxing the assumption of perfect competition for the interpretations of surplus based on derived demand.

#### 2.5.1 Marshallian Consumer Surplus

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[3] Recent work by (Bresnahan & Trajtenberg, 1991) and (De Long & Summers, 1991) suggests that there may be positive externalities to investments in machinery, especially high-tech equipment like computers. To the extent this is the case, the consumer surplus approach will underestimate the true contribution of IT, as would production function and business value metric approaches.

The most common conception of consumer surplus is based on ordinary (i.e. Marshallian) demand. As shown in figure 1, a price decline from $P_0$ to $P_1$ will be accompanied by a increase in quantity purchased from $Q_0$ to $Q_1$. The consumer surplus consists of two parts, the direct reduction in price on units that would have been purchased anyway (denoted by A) and the increase in welfare from additional units whose cost is now less than the consumers' willingness to pay (denoted by B).

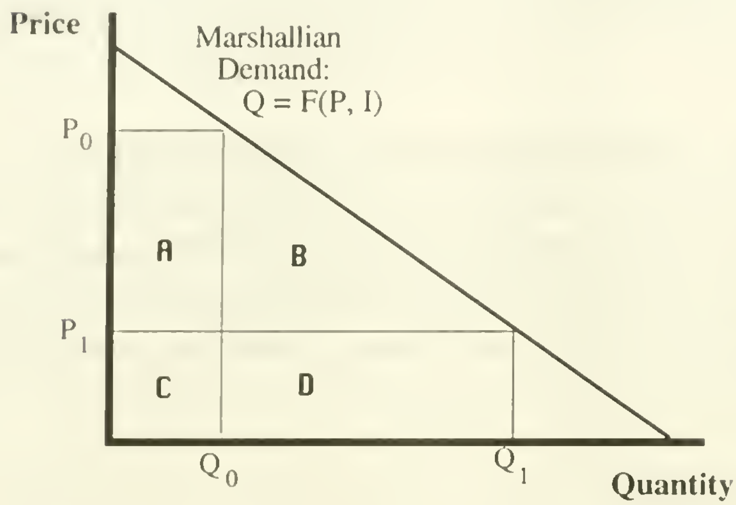



**Figure 1: Marshallian Consumer Surplus**

Given a specification for the demand curve, one can directly calculate Marshallian consumer surplus by integrating it between any two prices. In this paper, we use the log-linear specification given by equation 5. This is one of the most widely used functional forms for demand models (Oum, 1989). Its principal weakness is that it restricts the elasticities to be invariant for different quantities.[4]

$$q = e^{\gamma} p^{\alpha} y^{\delta} \qquad (5)$$

where $q$ = quantity
$p$ = price
$y$ = income
and $\gamma$, $\alpha$, and $\delta$ are parameters

[4] Fortunately, visual inspection of the raw data suggested that the demand curve for IT did have a remarkably constant elasticity regardless of scale, and the high $R^2$ obtained is consistent with this observation.

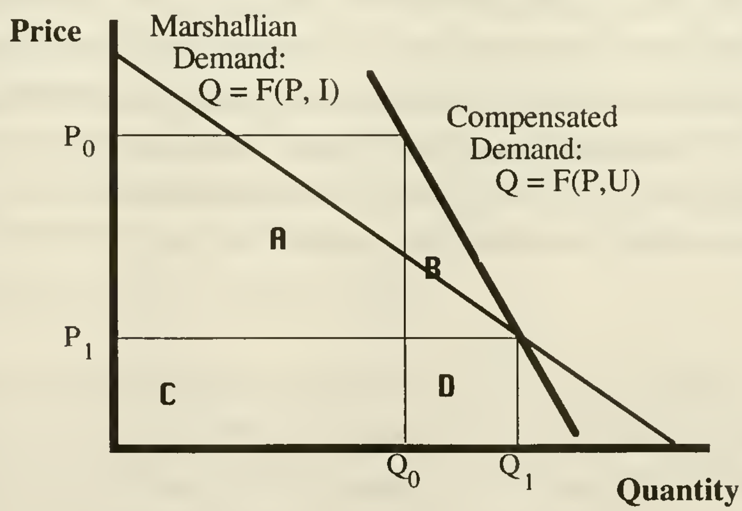
Integrating the demand curve from $p_0$ to $p_1$ yields:

$$e^{\gamma}y^{\delta}(p_1^{1+\alpha}-p_0^{1+\alpha})/(1+\alpha) \qquad (6)$$

Equation (6) can the be used to calculate surplus given prices and the parameters $\alpha$, $\gamma$ and $\delta$.

2.5.2 Exact Consumer Surplus

As pointed out by Hicks (1956), Marshallian consumer surplus is not an exact welfare measure. This is because a price decline in a good will increase the effective income available to the consumer and therefore shift the consumer to a higher utility curve. The appropriate demand curve to use for exact consumer surplus is the compensated demand curve, which is the amount that the consumer would demand if income were adjusted sufficiently to maintain the same utility level.[5] As shown in figure 2, a compensated demand curve will be steeper than the uncompensated demand curve, but the calculation of surplus is the same conceptually, the sum of areas A and B, now defined with reference to the compensated demand curve.




[5] Because, for a given income, the utility level at price $P_1$ is different from the utility level at $P_0$, there are actually two compensated demand curves which correspond to each end of the price change. In principal, exact surplus can be calculated with respect to either one of them, giving rise to a distinction between "equivalent variation" and "compensated variation". In this paper, I will focus on the latter for simplicity, although the former can be calculated analogously, and would little change the results.

**Figure 2: Compensated Consumer Surplus**

As with Marshallian consumer surplus, the value of the exact consumer surplus can be derived directly from a specified demand curve. In the log-linear case given by equation (5), the appropriate formula is given by (7):

$$\{(1-\delta)[e^{\gamma}(p_1{}^{1+\alpha}-p_0{}^{1+\alpha})/(1+\alpha)]+y^{(1-\delta)}\}^{1/1-\delta}-y \qquad (7)$$

The additional terms, as compared with (6) above compensate for the implicit change in real income due to the price change by taking into account the income elasticity of demand. For most goods, including IT, these terms will be of only second-order significance, so the Marshallian estimates are usually not a bad approximation of the exact consumer surplus (Willig, 1976).

2.5.3 A Non-parametric Derivation Consumer Surplus

The formulas above for Marshallian and Exact Consumer Surplus assume that the parameters of a functional form of the demand curve can be estimated. While this is generally possible, some error may be introduced in the estimation procedure, especially if the functional form chosen does not fit the actual demand curve well. An alternative approach is to explicitly add up each of the additional increments to consumer surplus from each price decline. For example, if the price decline from $P_0$ to $P_1$ can be decomposed into a number of smaller declines to intermediate prices labeled $P_t$, then the sum of price difference times the quantity increase for each intermediate step will be another measure of consumer surplus. For instance in figure 3, as in figure 1, area A denotes the addition to consumer welfare from a decline in price from $P_0$ to $P_1$ on infra-marginal units. Area E denotes the increase in welfare from the decline in price on the units between $Q_0$ to $Q_t$, labeled $\Delta Q$.[6]

[6] Area F will be of second order significance and can be ignored for small $\Delta Q$

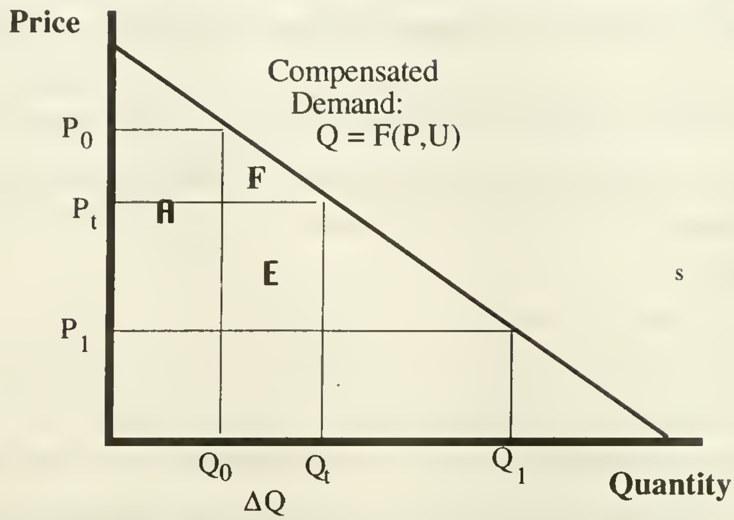



**Figure 3: Calculating Consumer Surplus Cumulatively**

If the steps ΔQ are made sufficiently small, this approach will be an arbitrarily good approximation of any monotonically decreasing demand curve, regardless of its exact shape. In the limit, of course, it is equivalent to integrating the area between $P_0$ to $P_1$. While this approach is more tedious than directly integrating the whole curve, it makes use of data on intermediate points which may not lie exactly on the equation for the estimated demand curve. The formula used for this approach is given by equation (8).

$$\Sigma\, (p_t - p_1)\, \Delta q_t\, (y_1/y_t), \text{ for } t = 0, \ldots, 1 \qquad (8)$$

where $p_t$ is the actual price in period t,
$\Delta q_t$ is the actual change in quantity from period t-1 to period t, and
$y_i$ = income in period t.

### 2.5.4 Applying the theory of index numbers

Consumer welfare is properly a function of the increase in utility from changes in prices and quantities. One can directly deduce the increase in welfare from assumptions about the form of the utility function, without making any direct assumptions about the form of the demand curve. Following Bresnahan (1986), we consider a translog utility function, which is one of the least restrictive available. Applying the theory of index numbers (Caves, Christensen & Diewert, 1982) we derive the increase in consumer welfare as given by equation (9).

$$1/2\ (s_{it}^{1} + s_{it}^{0})\ \log(p_0/p_1) \qquad (9)$$

where $s_{it}^{1}$ and $s_{it}^{0}$ are the factor shares of IT in periods 0 and 1 respectively

While each of these methods is slightly different, in principle, all four methods should yield similar estimates if the assumptions about the choice of functional form are correct.

## 3. Data and Methods

### 3.1 Data

We used two primary sources of data for this study: publicly-available data from the U.S. Bureau of Economic Analysis (BEA) on "office, computing and accounting machinery" for "OCAM" and for "OCAM PRICE" and a dataset on computer expenditures and prices which David Cartwright, a researcher at the BEA, compiled and provided to us, for "COMPUTERS" and "COMPUTER PRICE". In addition, we used government data on real gross domestic product for "GDP" and the GDP deflator for "INFLATION".

The OCAM data set consists primarily of computers, but also includes associated peripherals, electronic calculators and many other office machines. It does not include photocopiers, communications equipment, software, robots, or scientific instruments. The OCAM data are based on US National Income and Product Accounts annual investment expenditures and were allocated across industries using the BEA's capital flow tables. The data on two digit SIC industries were grouped into the following eight sectors: agriculture; mining; durable goods manufacturing; non-durables manufacturing; transportation and utilities; trade; finance, insurance and real estate; and other services. In addition, an aggregate was constructed for the economy as a whole.

A hedonic price index for OCAM was used to convert the current dollar flows to constant dollar flows. Thus the total number of units of OCAM purchased each year were made comparable to what they would have cost in 1982 based on features such as processor speed, memory, storage capacity, and display, weighted the relative proportions of the various types of equipment which comprise OCAM. The price index for OCAM, divided by the real GDP deflator, was used for the variable OCAM PRICE.

The separate data series on computers provided by Cartwright did not include the other types of office equipment that were included in OCAM. It also had its own hedonic price index which changed much more rapidly than the one for OCAM. However, these data were not available by industry, but only for the economy as a whole.

For gross income, we used GDP. Real GDP, in 1982 dollars, for each year was also compiled by the BEA for each of the eight sectors and for the economy as a whole.

The data are subject to a number of limitations. OCAM, COMPUTERS and GDP, and their associated price indexes, while based on the most authoritative source available, are each subject to measurement errors. Also, because the price index used for COMPUTERS was more recent, and significantly different from, the index used for OCAM, they are not directly comparable. Finally, all the data is at a fairly aggregate level, which will tend to obscure smaller trends in particular companies or of particular types of computers. However, this data should be useful for addressing questions like the overall contribution of OCAM and computers to the economy as a whole and in the eight sectors. Furthermore, the basic trends which are customarily ascribed to computers -- rapid price declines, significant growth in expenditures, and explosive growth in overall computer power delivered -- are all quite evident in this data as well. Intriguingly, when price and quantity are plotted on the same graph, the curve looks suspiciously like a demand curve, even before any estimation, corrections for income effects, etc. (see figure 4).

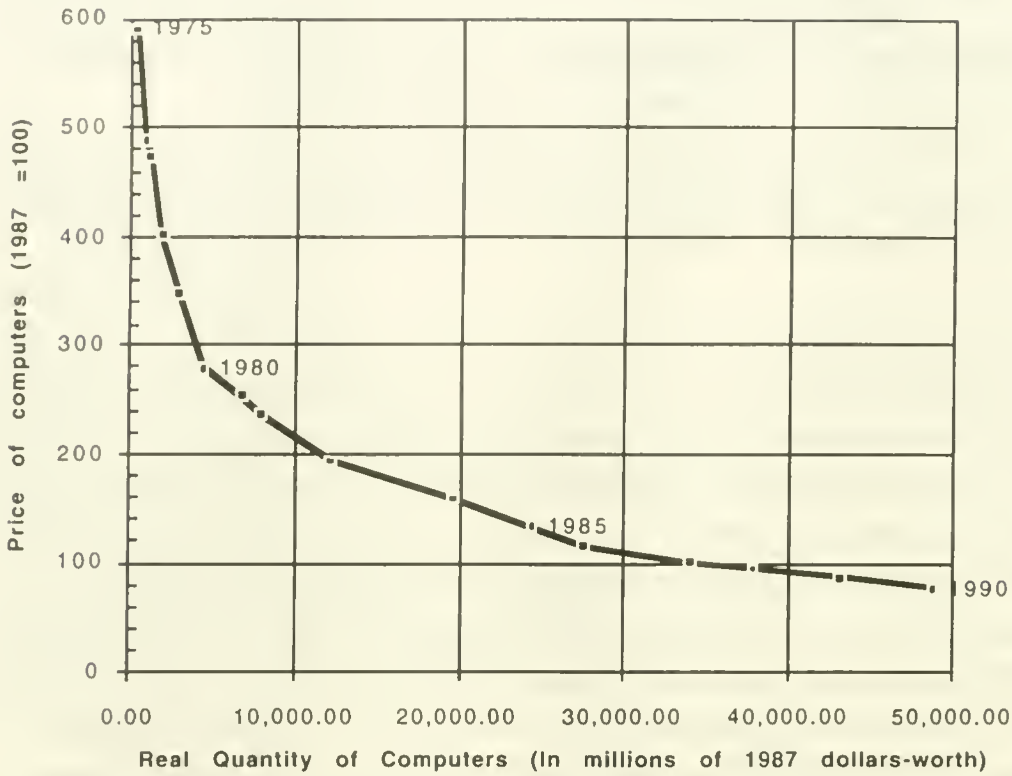



**Figure 4: Price and quantity for COMPUTERS**

<u>3.2 Methods</u>

3.2.1 Basic Estimating Equation

The key to our approach is getting sensible estimates of the demand for IT. The value for the price elasticity of demand is particularly important for the Marshallian and Exact consumer surplus calculations. The other two approaches are less demanding of the data. In fact, the index method requires only that starting and ending prices and quantities are known.

As described in section 2, for the first two approaches we assume that the relationship between prices and quantities can be described by equation (6). In order to estimate this equation, we take the log of both sides and include an error term, yielding:

$$\log q_{it} = \gamma + \alpha \log p_{it} + \delta \log y_{it} + \varepsilon_{it} \qquad (6)$$

where $q$ = quantity in sector i and year t,
$p$ = price in sector i and year t,
$y$ = income in sector i and year t,
$\gamma$, $\alpha$, and $\delta$ are parameters to be estimated, and
$\varepsilon_{it}$ is an error term assumed to be i.i.d.

A nice feature of this specification is that the coefficients, $\alpha$, and $\delta$, can be directly interpreted as the price and income elasticity of demand, respectively. Depending on the nature of the error term, $\varepsilon$, equation 6 can be estimated by Ordinary Least Squares (OLS) regression, which is the technique we used to estimate the demand function for COMPUTERS.

In order to take advantage the fact that we had distinct data for eight sectors on OCAM, OCAM price, and GDP, we estimated these eight equations simultaneously using the technique of Iterated Seemingly Unrelated Regressions (ISUR). We also made cross-equations coefficient restrictions to increase the efficiency of the estimation.

Because of the potential for serial correlation in time series regressions, generalized differencing was done for all equations by including a first-order autoregressive term in each regression.

3.2.2 Simultaneity: A natural experiment and instrumental variables estimates

The data we have document the relationship among the three variables (p,q,y) for each year and sector. The relationship is governed by the interplay of both supply and demand, giving rise to a problem of simultaneity which can make it difficult to identify which curve is being fitted.

In the case of OCAM and COMPUTERS, this problem is greatly alleviated by what amounts to a "natural experiment": due to extraordinary technological advances, the cost of supplying a unit of computer power has declined by over 6000-fold in the last 30 years (figure 5).

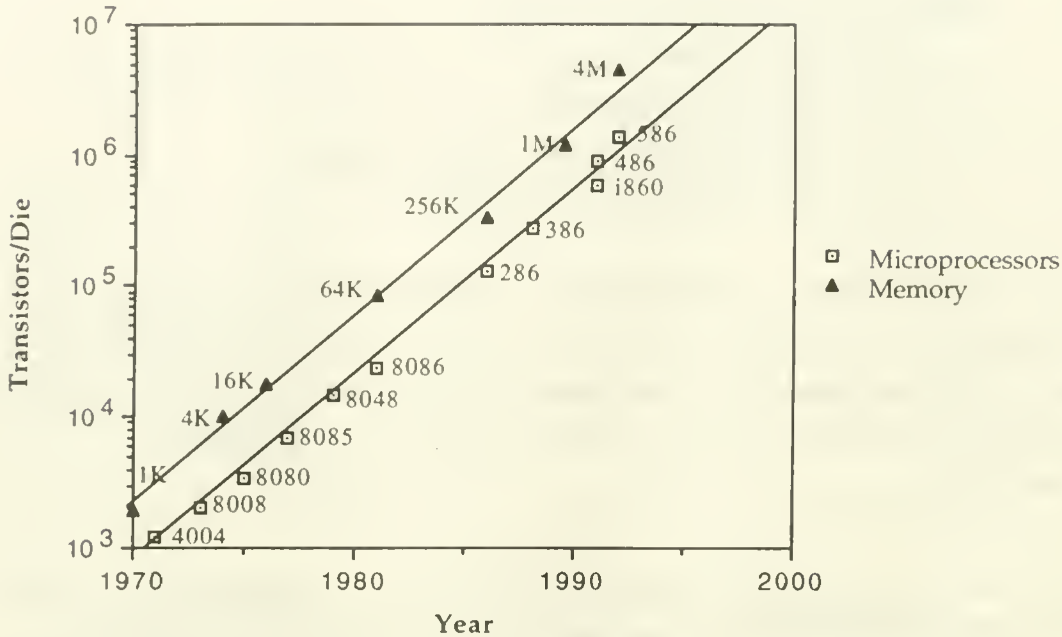



**Figure 5: Microchip performance has shown uninterrupted exponential growth.**

This has lead to a significant *shift* in the supply curve each year, which effectively "maps out" the underlying demand curve, since demand has presumably shifted much more slowly (see figure 6). For most products, economists can only speculate as to how much of the good would have been demanded if the price were 2, 10 or 100 times the current price. In the case of IT, we have historical evidence of what actually was demanded at such prices.

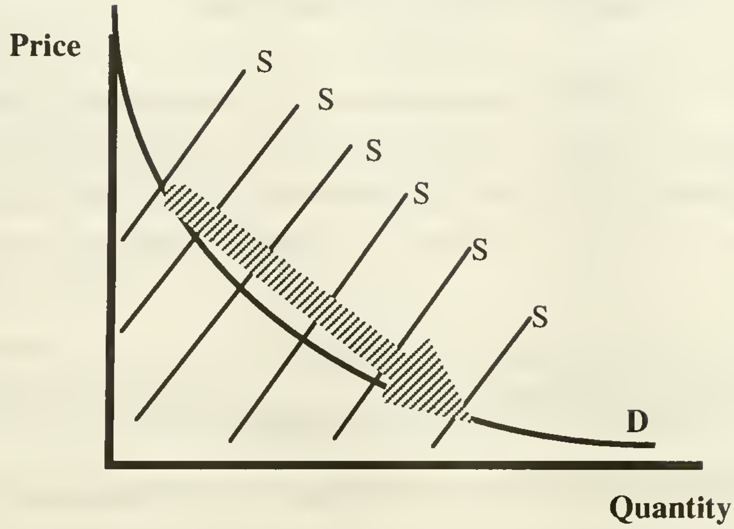



**Figure 6. The "natural experiment" of shifting supply curves.** Only the intersections of supply and demand are observed, but if the supply curve (denoted "S") shifts, then the demand curve (D) is revealed.

Presumably demand, too, has shifted over time, but it is likely that shifts in demand are orders of magnitude smaller than movements along the demand curve. For instance, Gurbaxani and Mendelson (1990) considered the alternative hypotheses that the increase in computer demand was either due to diffusion or declines in price. They concluded that since 1970, essentially all of the increase has been due to price declines. Likewise, Gurbaxani (1992) estimated a model which included a shift parameter to account for the diffusion of technology over time, but found that it added essentially nothing to the regression that included price and income effects. Accordingly, we follow the tradition pioneered by Chow (1967) of focusing on price and income effects to explain computer demand.

We discuss how our results would be affected by unmeasured shifts in demand in section 4.3. In addition, as a check on the reasonableness of our estimates using ISUR, we also estimated the equations using Three Stage Least Squares (3SLS). This technique is designed to use instrumental variables to filter out endogenous variation in the independent variables.

Obviously, for the non-parametric method and the index approach, econometric estimation of the demand curve was not necessary.

## 4. Results

4.1 Regression estimates of the demand for COMPUTERS and OCAM

We estimated the demand for COMPUTERS using equation 6 by the method of OLS with a correction for serial correlation for 1970 to 1990 (21 observations). Price elasticity was estimated at -1.33, income elasticity at 3.45 and the constant was -42.08 (see table 1). All estimates were significant at no less than 95%, with the price elasticity significant at over 99%. The $R^2$ was 99%.

| Sector | price elasticity | income elasticity | constant |
|---|---|---|---|
| Economy | -1.33 | 3.43 | -42.08 |

**Table 1: Elasticity estimates for economy-wide demand for Computers**

The results for the system of equations on OCAM by sector and for the single equation for the economy as a whole are given in table 2. In order to correct for potential serial correlation while still making the problem solvable by our econometric software, we had to restrict one coefficient to be constant across sectors in the system of equations, so we restricted income elasticity.[7] An inspection of the residual for the equation for the economy as a whole revealed several outliers in the 1974-1976 time period, possibly due to changes in the calculation of the BEA's price index for these years. Therefore, we also report results on the economy as a whole for the period 1977 to 1990.

The estimates for price elasticity varied by sector, ranging from about -1 in Mining to about -1.7 in Non-Durable Manufacturing. Services, including Trade, Finance, Insurance and Real Estate, and Other Services tended to be less price-elastic than manufacturing and transportation and utilities. The estimates for the economy as a whole were surprisingly different from the average of the sectors, probablv because fewer data were available for the single equation estimation of the economy-wide elasticities than for the system of equations for the sectors. This made the economy-wide regression particularly susceptible to the outliers in the 1974-1976 period. All of the coefficients were significant at the 95% level of confidence, with the exception of the constant term in the two economy-wide regressions. In the system of equations for the sectors, the price elasticity estimates were all significant at over the 99% level.

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[7] Given the large changes in IT prices and the relatively small changes in income over the sample period, it seemed more sensible to retain as much sensitivity to price movements as possible.

| Sector | price elasticity | income elasticity | constant |
|---|---|---|---|
| Agriculture | -1.43 | 1.03 | -8.42 |
| Mining | -0.99 | 1.03 | -6.69 |
| Durable Mfg. | -1.40 | 1.03 | -4.86 |
| Non-Durable Mfg. | -1.71 | 1.03 | -5.30 |
| Transport & Util. | -1.57 | 1.03 | -5.47 |
| Trade | -1.28 | 1.03 | -5.29 |
| Finance, Ins. & RE | -1.15 | 1.03 | -4.16 |
| Other Services | -1.07 | 1.03 | -5.33 |
| | | | |
| Economy | -0.57 | 2.06 | -16.45 |
| Economy, 1977-90. | -0.93 | 1.71 | -14.81 |

**Table 2: Elasticity estimates by sector and for the economy for OCAM**

We also ran the system using the 3SLS to correct for potential simultaneity. Although the demand elasticities were slightly lower, as expected, the results using this approach were not significantly different from the ISUR estimates.

4.2 Consumer Surplus Calculations

As a representative year for our welfare calculations, we chose 1987. GDP (income) by sector and spending on OCAM is given in table 3.[8]

| Sector | 1987 GDP | 1987 OCAM |
|---|---|---|
| Agriculture | $ 105,100 | $ 32 |
| Mining | 305,000 | 694 |
| Durable Mfg. | 515,600 | 6,891 |
| Non-Durable Mfg. | 336,600 | 2,349 |
| Transport & Util. | 371,300 | 2,617 |
| Trade | 655,900 | 5,517 |
| Finance, Ins. & RE | 560,600 | 15,485 |
| Services | 592,600 | 7,579 |
| *sum of 8 sectors* | *3,442,700* | *41,164* |
| | | |
| Economy | 3,442,700 | 41,164 |

**Table 3: GDP and OCAM Spending by sector.**
(in millions of 1982 dollars.)

[8] Spending on COMPUTERS in 1987 was approximately $25 billion.

Applying the methods described in section 2.5 and the regression results of section 3.1, we derived estimates of the surplus for COMPUTERS and OCAM for 1987.[9] Table 4 gives estimates using equations 7, 8, 9, and 10 respectively for COMPUTERS. Surplus is estimated at between $69 billion and $73 billion, which, when compared with $25 billion in spending, suggests that consumers keep about three out of every four dollars of gross value created by computers. (The total gross value generated is equal to consumers' surplus plus expenditures.)

| Marshallian Surplus | Exact Surplus | Cumulative Method | Index method |
|---|---|---|---|
| $70,574 | $73,178 | $69,052 | $70,175 |

**Table 4: Consumer Surplus estimates for COMPUTERS.** The figures are the surplus created for consumers by the price decline in COMPUTERS between 1970 and 1987, in millions of 1982 dollars.

The estimates are all remarkably consistent, despite the different methods used to derive them. The closeness of the Marshallian and Exact estimates of consumer surplus are consistent with the claim of Willig (1976) that for most goods, income effects are relatively small and can be ignored without much loss of precision. The fact that the cumulative method is also close to the first two estimates springs from the good fit of the regression used to estimate demand, whose parameters were used in equations 7 and 8. The index method is not based on any explicit assumptions about demand, but does assume a translog utility function, which can give rise to the log-linear demand function we estimated.

Table 5 gives estimates using equations 7, 8, 9, and 10 respectively for OCAM, by sector and for the economy as a whole.

[9] Note that the estimates of consumer surplus derived in this paper are underestimates of the total surplus since they do not consider the portion of the welfare triangle associated with price declines which occured before 1970. Although these declines may be as large as subsequent declines, they apply to a far smaller quantity of computers, and thus the values derived in this paper should not be far from the "true" values.

| Sector | Marshallian Surplus | Exact Surplus | Cumulative method | Index method |
|---|---|---|---|---|
| Farming | $50 | $50 | $64 | $46 |
| Mining | 790 | 791 | 2,012 | 1,001 |
| Durable Mfg. | 9,061 | 9,143 | 11,129 | 9,942 |
| Non-Durable Mfg. | 4,020 | 4,044 | 3,508 | 3,389 |
| Transport & Util. | 3,612 | 3,630 | 2,905 | 3,776 |
| Trade | 7,343 | 7,386 | 10,997 | 7,960 |
| Finance, Ins. & RE | 19,044 | 19,381 | 16,898 | 22,342 |
| Services | 6,166 | 6,199 | 7,446 | 10,935 |
| *sum of 8 sectors* | *50,086* | *50,625* | *54,960* | *59,392* |
| Economy, (using 1970-1990 regression estimates) | 2,757,094 | 16,794,771 | 57,179 | 59,392 |
| Economy, (using 1977-1990 regression estimates) | 74,732 | 76,141 | 57,179 | 59,392 |

**Table 5: Consumer Surplus estimates for OCAM by sector and for whole U.S. economy.** The figures are the surplus created for consumers by the price decline in OCAM between 1970 and 1987, in millions of 1982 dollars.

For OCAM, as for COMPUTERS, most of the estimates of consumer welfare are fairly consistent with one another. The exception is the estimates of Marshallian and Exact surplus estimates for the economy as a whole when the years 1970-1976 were included. This can be directly attributed to the relatively poorly fitting regressions used to derive the required parameters. The sector with the largest surplus by all methods was Finance, Insurance and Real Estate, which ironically is not only a sector with minimal measured productivity gains according to official statistics, but also one with among the worst measures of output.

When the surplus from each of the eight sectors is summed, the total is about $50 billion, not far from the estimates of the economy as a whole using the cumulative and index methods, but significantly less than the estimates based on the regressions for economy-wide OCAM demand (i.e. the Marshallian and Exact surplus).

When the OCAM and COMPUTERS estimates are compared, it is surprising to note that more surplus is generated by COMPUTERS than by their superset OCAM, which is supposed to include all computers as well as certain other goods. One might be tempted to conclude that the additional goods in OCAM, such as hand calculators, actually *subtract* from welfare. However, a simpler explanation exists. As mentioned in section 3, the price index used for COMPUTER was more recent and showed substantially greater

improvements in price/performance than the one used for computers in OCAM. According to Allan Young, the director of the BEA, the government eventually intends to adopt the COMPUTER price index, created by Cartwright (1986), for OCAM as well. When this is done, we would expect the estimates for consumer surplus from OCAM to increase commensurably.

4.3 Sensitivity analysis

The Marshallian and Exact estimates of consumer surplus are relatively robust to changes in the estimates for the price elasticity of demand: 50% changes in price elasticity lead to less than 10% changes in the surplus estimates. On the other hand, they can be quite sensitive to the parameters for income elasticity and the constant term, which shift the entire locus of the demand curve. This underscores the value of using multiple measures of consumer surplus to avoid undue influence of any one data point.

A more interesting type of sensitivity analysis is to consider an outward shift in the entire demand curve. In particular, our estimates do not include any parameter to account for diffusion of the technology: we attributed the increase in quantities purchased over time entirely to lower prices and greater income. While, as we noted in section 3.2.2, this approach has a long tradition, it is interesting to consider how much our results would change if we attribute some of the growth in IT to diffusion. To examine how this would affect our results, we assumed that COMPUTER and OCAM would have grown by 2% per year even if the price had been constant. The net effect of this assumption is to shift the demand curve outward from what we observed. The top, which is based on data from 20 years ago, is shifted out far more (i.e. by about 50%) than the bottom, which being based on more recent purchase decisions presumably already reflects past diffusion. Under this assumption, the consumer surplus from computers is found to increase by about 20%, regardless of the method used.

A third type of sensitivity test is to relax the fundamental assumption of consumer surplus estimation that the marginal value to the purchasers of a good is equal to the price the purchasers were willing to pay for the last unit. If for some reason, (the modeling of which is beyond the scope of this paper), managers systematically spend too much on IT, then, by definition, they would not be getting their money's worth for the last units they buy. However, the infra marginal units could still be adding to welfare. To be specific, suppose that OCAM and COMPUTERS only generated 80 cents of value for each dollar

spent on the margin. This is consistent with an estimate by Morrison and Berndt (1990) regarding the marginal productivity of "high tech" capital in manufacturing industries. This would shift the demand curve downward by 20% and thereby would reduce the gross value (consumer surplus plus expenditures) created by OCAM and by COMPUTERS to about $80 billion. Under this scenario, we find that OCAM and COMPUTERS would be adding $40 billion to $50 billion more to welfare than they cost, for a net gain.

In fact, if computers and OCAM delivered on average only half of the benefits that managers expected when they made their investments, there would still be a gain from computerization of between $10 billion and $20 billion in 1987. Our consumer surplus estimates indicate that computers and OCAM would have been a net positive contribution to the U.S. economy unless managers have been getting an average of less than 25 cents for each marginal dollar invested in COMPUTERS and 40 cents for each marginal dollar invested in OCAM.

Of course, it is also possible that managers have been doing better than breaking even on their marginal investments in IT. According to Brynjolfsson and Hitt (1993), the gross marginal return on investment (ROI ) for IS capital averaged over 50% in the 1987-1991 time period for their sample of 380 large firms. If one assumes a five year average service life and a linear decline in ROI over that time to account for depreciation,[10] firms would be creating $1.25 of additional net output for each dollar invested on the margin. This suggests that actual consumer surplus from OCAM and COMPUTERS could be as high as $80 to $90 billion per year.

Finally, we also examined several base years other than 1987. In each case, the value of consumer surplus was about 3 times expenditures for COMPUTERS and about equal to expenditures for OCAM. This consistency can be attributed to the fact that the percentage declines in IT prices and increases in quantities purchased have been remarkably uniform since 1970. Data for each year look like data for any other year, except for a proportional "rescaling" of the axes. One implication of this finding is that in the 1960s, 1970s and through the mid-1980s, computer spending and computer surplus were relatively small as compared to total GDP, and therefore were not likely to have had measurable effect, one way or the other, on the "productivity slowdown" at the level of the whole economy. In the past few years, computer spending has grown to a magnitude at which one should

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[10] These are admittedly somewhat arbitrary assumptions, but they are meant only for illustrative purposes.

begin seeing impacts even in output and productivity statistics for the U.S economy as a whole. Specifically, our calculations indicate that computerization added about 0.2% to 0.3% to GDP growth in 1987.

The growth in computer spending and surplus as has been essentially exponential in the past, and if it continues to be exponential, this implies a continuing increase in the absolute value of consumer surplus in the future. For example, if one extrapolates the trends in computer spending, and assumes GDP growth of 2% per year, one can estimate that by 1997, total consumer surplus from COMPUTERS will be nearly $400 billion per year. The comparable figure for OCAM is a surplus of about $200 billion. The lower number for OCAM surplus is due to the much slower decline in the OCAM price index compared to the COMPUTER price index (14% per year vs. 25%).

## 5. Conclusion

### 5.1 Summary

This paper presents some estimates of the contribution of IT to consumer surplus. We applied four different methodologies to data from two different sources and conducted a number of sensitivity analyses. Our estimates indicate that in 1987, OCAM and Computers added between $50 billion and $70 billion to consumer welfare, after expenditures were subtracted, and that the contribution is growing steadily over time. Our estimates using the different methods were fairly consistent with one another and reasonably robust to changes in the underlying assumptions or data.

This approach provides a new perspective on the IT value debate. It should be emphasized, however, that this methodology does not directly address the question of whether managers and consumers are purchasing the right quantity of IT, but rather takes their preferences as given. For instance, the discrepancy between the large consumer surplus implied by the methodology used in this study and the minimal productivity impact found in some other studies may be due not only to mismeasurement of output, but also to systematic over-consumption of IT by managers.

### 5.2 Extensions

The estimates derived should be considered only a first step toward determining the consumer surplus from IT. There are at least five extensions that can be pursued in future papers.

First, one could explicitly control for more factors other than price and income. For instance, including a diffusion or learning curve parameter, considering computer stocks instead of flows, and estimating a more general functional form for demand are three ways to improve the econometrics.

Second, it may be possible to secure data which is disaggregated further by industry, by type of computer, or for new time periods.

Third, computers are a complementary input for software, telecommunications, the information in databases, and even business process redesign. Since each of these variables has grown rapidly over time, theory suggests that part of their growth may be fairly attributed to price declines in computers. In principle, the welfare effects of this growth, and the share that is related to computer price declines, can be calculated.

Fourth, surplus from derived demand is a good estimate of final consumer surplus if markets are competitive and there are no externalities. However, the extent of monopoly power and technological spillovers can be explicitly estimated and used to improve the welfare estimates.

Finally, it would be interesting to compare the contribution from IT implied by the consumer surplus estimates with the contribution implied by other techniques, such as production functions. Any differences found may shed light on the nature of measurement error, or other problems with one or the other method.

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